AUV Navigation Investment Strategy Roadmap

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LONG-TERM GOALS

Navigation is one of the fundamental roadblocks to development of AUV technology today. Improved navigation and coordination of multiple vehicles is essential to reduce space-time aliasing and increase the efficiency and effectiveness of ocean mapping and reconnaissance using AUVs. However, current navigation sensors for low-cost vehicles are inadequate for many mission objectives to be met. The ultimate goal is to create a generic, flexible, intelligent, cost-effective navigation capability for the widest range of AUV platforms and missions possible.

OBJECTIVES

The objective of this project has been to define a roadmap for future investments in AUV navigation technology for the next seven years. Based on consultation with major AUV technology developers in academia, industry, and the Navy labs, our task has been to deliver an assessment of the current state-of-the-art in AUV navigation and to make a projection of what advances in autonomous operations are possible in the next seven years.

APPROACH

We have evaluated current technologies in key areas of inertial navigation systems (INS), Doppler velocity sonar (DVS), Kalman filtering (KF), long baseline (LBL) and ultra-short baseline (USBL) acoustic navigation systems, GPS, feature-based navigation algorithms, and multiple vehicle operations. We have projected the development of technology in these areas over the next seven years. We have evaluated the needs and constraints of four different mission capabilities: (1) station-keeping, (2) area search, (3) long-distance traverse, and (4) feature tracking. Of these, we have focused most of our efforts on the first two requirements. This document provides a brief summary of our recommendations.

WORK COMPLETED

An evaluation of current technologies and projection of future developments has been completed in the following key areas: INS/DVS/KF, LBL and USBL acoustic navigation systems, GPS, feature-based navigation algorithms, and multiple vehicle operations. Our work involved extensive consultations with practioners in industry, government, and industry, careful study of the literature, and computer simulations.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **AUV Navigation Investment Strategy Roadmap**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Massachusetts Institute of Technology,,Cambridge,,MA, 02139**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

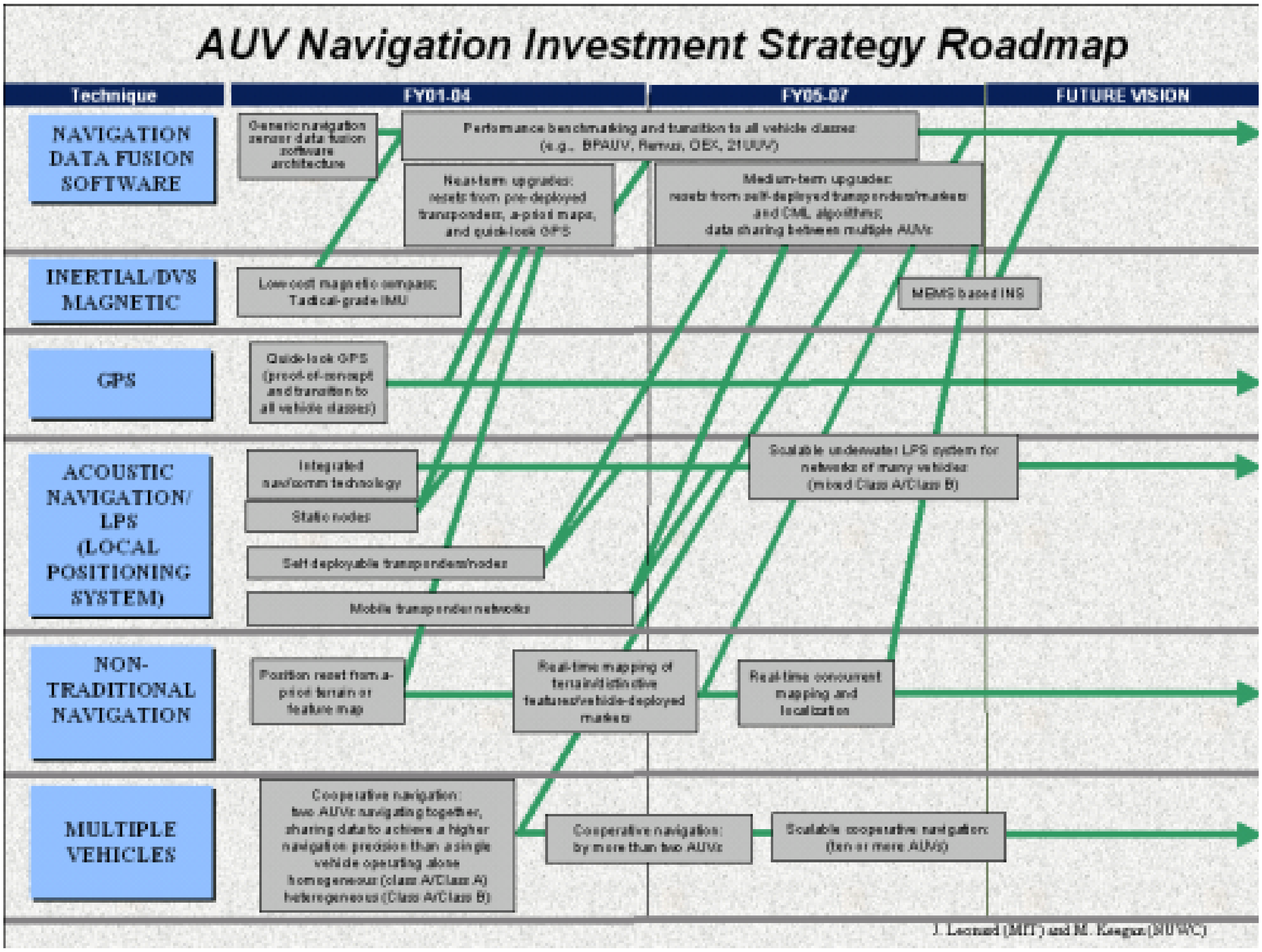
13. SUPPLEMENTARY NOTES

14. ABSTRACT
Navigation is one of the fundamental roadblocks to development of AUV technology today. Improved navigation and coordination of multiple vehicles is essential to reduce space-time aliasing and increase the efficiency and effectiveness of ocean mapping and reconnaissance using AUVs. However, current navigation sensors for low-cost vehicles are inadequate for many mission objectives to be met. The ultimate goal is to create a generic, flexible, intelligent, cost-effective navigation capability for the widest range of AUV platforms and missions possible.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18



RESULTS

Figure 1 provides a summary of our recommendations. For long-distance transit, the highest priority task for investment should be the creation of a generic navigation sensor data fusion software architecture that is collaboratively developed and widely disseminated to the AUV research community. The navigation software should be made available for a variety of different types of AUVs. A number of navigation Kalman filters for integration of INS and DVS information have been previously developed under a range of Navy programs (e.g., DARPA AMMT, NUWC LDUUV/21UUV). However, the amount of testing performed with these systems has been limited, and the products have not been transferred to smaller AUV platforms. We envision the generalization of this type of filter to incorporate position information from a variety of sources, including quick-look GPS and pre-deployed transponders (short-term), and self-deployed transponders/markers and measurements/position information from other vehicles (medium-term). The navigation sensor data fusion architecture should also allow the integration of position resets from maps provided a priori to the AUV or autonomously generated during the mission via concurrent mapping and localization (CML).

At-sea performance testing and validation with independently determined ground truth are vital; a significant percentage of available resources should be devoted to performance benchmarking.

The navigation filter should be transferred to and tested on a wide range of platforms. Tools should be developed for using ground-truth to develop better error models and to enable automatic calibration. Navigation performance will of course depend on the quality of vehicle organic navigation sensors. We envision three categories: Class A (INS/DVS), Class B (Compass/DVS), and Class C (Compass/Attitude). For long-distance transit missions, there is no alternative but to pay for a class A system. We have studied in detail the costs and capabilities of the four primary suppliers of INS systems: Kearfott, Litton, Honeywell, and L3 (formerly Allied Signal). The Litton LN250 is attractive for its small size and potentially low cost. (current cost of approximately $100,000/unit, with a projected cost of approximately $40,000/unit in the near future). Field test results for this system working with an RDI Doppler should be available in the near future from the Bluefin Cornerstone Navigator project. Kearfott RLG INS systems can be obtained in a size suitable for a small vehicle at a cost of approximately $80,000, with the Kalman filter included. The RDI Doppler currently costs approximately $25,000, and in quantity one could expect a price drop to $10,000. Sontek currently sell a DVS for about $10,000.

The current state-of-the-art for long distance transit missions is a position accuracy of about 0.1% of distance traveled. While some claims for better performance have been made in the literature, we see the consistent realization of 0.1% on a wide range of platforms as a significant achievement and the appropriate performance target for the short-term. This performance limit comes primarily from uncertainty in the Doppler velocity scale factor, and most people agree that this is a "hard" performance boundary that is difficult to push back. Surpassing this performance target may be possible in the medium-term through a great deal performance testing and the development of tools for error modeling and automatic calibration.

The Navy UUV master plan calls for long distance transmit missions of 100 nautical miles. For this distance, an error of 0.1% of distance traveled translates into roughly 200 meters error, which is probably unacceptable for most missions. Hence, there is a need to perform position error resets. Each of the available technologies to perform resets -- GPS, acoustic transponders, and map-based/feature-based navigation -- suffers from various shortcomings, and the decision is not easy. For the AOFNC program we believe that the first priority should be to develop "quick look" GPS. With quick-look GPS, satellite ephemeris data is stored on the vehicle before launch of the mission. The time required at the surface to get the data necessary for a fix is reduced to less than one second.

There is a possibility that some missions will require completely covert long-distance traverses, without surfacing for GPS resets of any kind. For this reason, we have included position resets from non-traditional navigation techniques in the roadmap. However, the funding of field tests for these capabilities is given a lower priority, because of the problem of reliance on an a priori map.

Suggested priorities for long-distance transit:

FY 02-03:

1. Field deployment and performance benchmarking of INS/Doppler aided systems to demonstrate 0.1% of distance traveled accuracy with a sensor cost of $125,000 per vehicle (hardware, INS: Litton LN250 and/or Kearfott RLG; Dopplers sonar: RDI and/or Sontek).
2. Development and field testing of quick-look GPS.
3. Integration of position resets from pre-deployed transponders.

FY 04-05:
1. Transition of 0.1 % of distance traveled INS/Doppler capability to all vehicle classes; performance benchmarking.
2. Integration of position resets from autonomously deploeyed transponders/markers.
3. Integration of position resets from an a-priori map.

FY 06-07:
1. Improve error metric to 0.05% of distance traveled or better through development of technologies for automatic self-calibration and bias compensation.
2. Demonstration of multi-vehicle long distance transit missions involving sharing of position information between vehicles (e.g. transit through deep-water with one vehicle surfacing for GPS fix and the other vehicle maintaining Doppler bottom lock).
3. Development of concurrent maping and localization algorithms using terrain features detected with organic sonar sensors during the mission.

Future vision (post FY07):
- .01 % of distance traveled (20 meter error after 100 nmi transit)
- automatic alignment/self-calibration of biases/alignment errors/scale factors through observations of targets and the application of concurrent mapping and localization technology for precision auto-calibration of INS/DVS bias parameters at the start of a mission.
- low-cost class A system using MEMS-based INS.

For large-scale area search and mapping missions, we advocate the pursuit of a new paradigm for AUV operations that generalizes current LBL/USBL acoustic navigation to create dynamic, self-deploying and self-calibrating arrays of vehicles and nodes. This can be thought of as an underwater LPS (local positioning system) system. Mobile nodes are envisioned as other AUVs or as inexpensive disposable transponders with propulsion (such as an EMatt) who might be air-dropped, thrown off the side of a ship, or launched from a "mother-ship" AUV.

Clearly, by using multiple vehicles, there is the potential to map an unknown environment more effectively, quickly, and robustly than with a single vehicle. The novel challenges and opportunities of multiple vehicle operations are particularly exciting, and we feel that the time is right for a strong push in this area. In particular, a key component of the roadmap is to demonstrate multiple vehicles navigating together and sharing globally referenced position information, with accompanying uncertainty bounds. For many vehicle scenarios, it will be important to develop lower-cost class B and class C navigation solutions using magnetic compass and attitude-heading measurements systems. For this reason, field deployment of improved magnetic heading measurement technologies such as the MTI SBIR project is considered a desirable short-term milestone. Further work is necessary to determine the right mix of assets between static or mobile nodes and AUVs with class A, B, and C navigation systems.

The nav/comm aid concept is defined in the UUV Master plan as a UUV that connects RF/Satcoms/GPS with Acoustic Communications. These vehicles are envisioned as communication and navigation nodes to assist in transferring data and position and control information between vehicles and controlling personnel. One possiblity is that nav/comm. aid vehicles can be equipped with class A navigation systems, and can transfer position uncertainty through the network to class B and C vehicles. This will require generalization of the single vehicle navigation sensor data fusion architecture to accommodate uncertainty management for position information being transferred back and forth by multiple nodes in the network.

Suggested priorities for area search:

FY 02-03:
1. Development of "integrated nav/comm package" to be installed on static/mobile nav/comm aid nodes and vehicles.
2. Field demonstration of cooperative navigation by two vehicles. (Both homogeneous class A/class A and heterogeneous class A/class B).
3. Development and field-testing of low-cost precision magnetic heading measurement technologies.

FY 04-05:
1. Field demonstration of use of nav/comm aids for underwater GPS.
2. Field demonstration of cooperative navigation by three vehicles utilizing data sharing between vehicles to obtain increased precision.

FY 06-07:
1. Field demonstration of a scalable cooperative navigation solution suitable for use by ten or more AUVs.

Future vision (post FY07):
- scalable architecture for dynamic, autonomously-deployed, many vehicle/node navigation networks.

TRANSITIONS

In general the navigation capabilities demonstrated by the AO FNC have the potential to transition to a variety of programs, such as:

- NAVOCEANO's UUV for TAGS ships
- Semi-Autonomous Hydrographic Reconnaissance Vehicle
- Search Classify Map Vehicle
- Reacquire Identify and Neutralize Vehicle
- Long-Term Mine Reconnaissance System (AN/BLQ-11)
- Mission Reconfigurable UUV (MRUUV)

RELATED PROJECTS

Generic Ocean Array Technology Sonar (GOATS): The objective of the GOATS project (PI: Henrik Schmidt) is to create a new paradigm for sensing the ocean environment using multi-static acoustics combined with networks of AUVs. A key element of GOATS is to implement precision cooperative navigation of multiple AUVs. The Roadmap developed under this project provides some of the guidance and motivation for this work. In conjunction with NATO SACLANT Undersea Research Centre (PI: Edoardo Bovio), field trials planned with the NRV Alliance in May, 2002 will seek to demonstrate concurrent mapping and localization running on-board onboard a single AUV using transponders as features. In addition, cooperative navigation by two AUVs will be demonstrated.

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